Network EducationWare: An Open-Source Web-Based System for Synchronous Distance Education

Charles Snow, *Member, IEEE*, J. Mark Pullen, *Fellow, IEEE*, and Priscilla McAndrews

***Abstract*—Inexpensive computers and Internet connections can be used in teaching engineering and technology courses to make the classroom presentation of a lecture available anywhere with connectivity. With rapidly growing demand, particularly from working professionals who need courses to remain current or for advancement in their careers, and reductions in financial support, universities face increasing pressure to find solutions that are effective academically and fiscally. This paper describes an open-source distance-learning system that fulfills both "smart classroom" and distance-education roles and that is inexpensive, easy to use and operate, and highly effective, even when used over dial-up connections. The software is available at no cost for academic use.**

***Index Terms*—Distance learning, online learning, synchronous learning, Web.**

I. INTRODUCTION

INSTRUCTION in engineering and technology fields is dominated by traditional classroom lecture presentations [1]. These range from an instructor and handwritten material on a blackboard to computer-generated presentations with commercial products like Microsoft's PowerPoint. This setting requires students to be physically present on campus at the time of the lecture. Students attending a lecture benefit from interaction with each other and the lecturer.

While the overall presentation of most courses remains lecture oriented, many organizations make increasingly productive use of the Internet, and the World Wide Web in particular, to make available supplemental and/or complementary course-related material to students; 90% of organizations using the Internet as an instructional tool provide this type of asynchronous access [2]. A good example of this type of service is OpenCourseWare[1] by the Massachusetts Institute of Technology (MIT), Cambridge.

A complementary trend in deployment of technology, though not necessarily of the Internet, is toward the "smart classroom." Typically such classrooms integrate computer-generated presentations, and possibly Web content, with annotations for display within the classroom. In some cases, the presentations may be recorded for future playback. The main drive in development of smart classrooms is effective deployment of computer technology to enhance the classroom teaching (and, one hopes, learning) experience [3].

Network EducationWare (NEW) is a system combining the two trends described above, providing students with the means to actively participate synchronously with live classes and/or asynchronously with recordings of the classes. In addition, NEW meets a demand from a growing student constituency—telecommuters—at a cost comparable to classroom instruction.

Postsecondary educational institutions offering engineering and technology programs face increasing demand from a student demographic characterized by working professionals [4]. These individuals often are seeking further training (to remain current in their field or expand their expertise) or additional certification (certificates, diplomas, degrees). These students already make heavy use of course-related material available from course Websites. One demand of this demographic is access to courses outside normal teaching hours, and, increasingly, without requiring the student to be physically present. This demand is felt keenly in urban areas, where traffic congestion can make classes difficult to reach. These students would prefer to participate in a class from their home or place of work which often requires using a computer behind a firewall.

Demand for distance education is expected to grow rapidly worldwide. An estimate of overall student enrollment in college-level distance-education courses in the United States was just under 3 million in 2001 [4]. In 2003, over 50% of people at least 16 years of age were involved in undergraduate- or graduate-level work-related education [5]; more and more of these will be learning online. The use of distance learning is viewed by 67% of schools as critical to a long-term strategy [6]. This same survey indicated that 75% of schools believed that learning outcomes were as good as or better using distance education than face-to-face teaching. Growth in the use of distance course delivery in the one year between 2002 and 2003 is reported to be almost 20% [6]. While overall enrollment in degree-granting institutions is expected to grow by at least 15% over the ten-year period ending in 2013, the fastest growing segment of that student population is "first time professionals," projected to increase by 27% [7].

The challenge posed by this growing demand is how to provide these students with the essential qualities of being present in a live classroom lecture, delivered using the Internet. What features of the live classroom experience are (and are not) crit-

Manuscript received August 2, 2004; revised March 1, 2005. This work was supported by the U.S. National Library of Medicine and the U.S. Joint Forces Command through the Virginia Modeling, Analysis and Simulation Center.

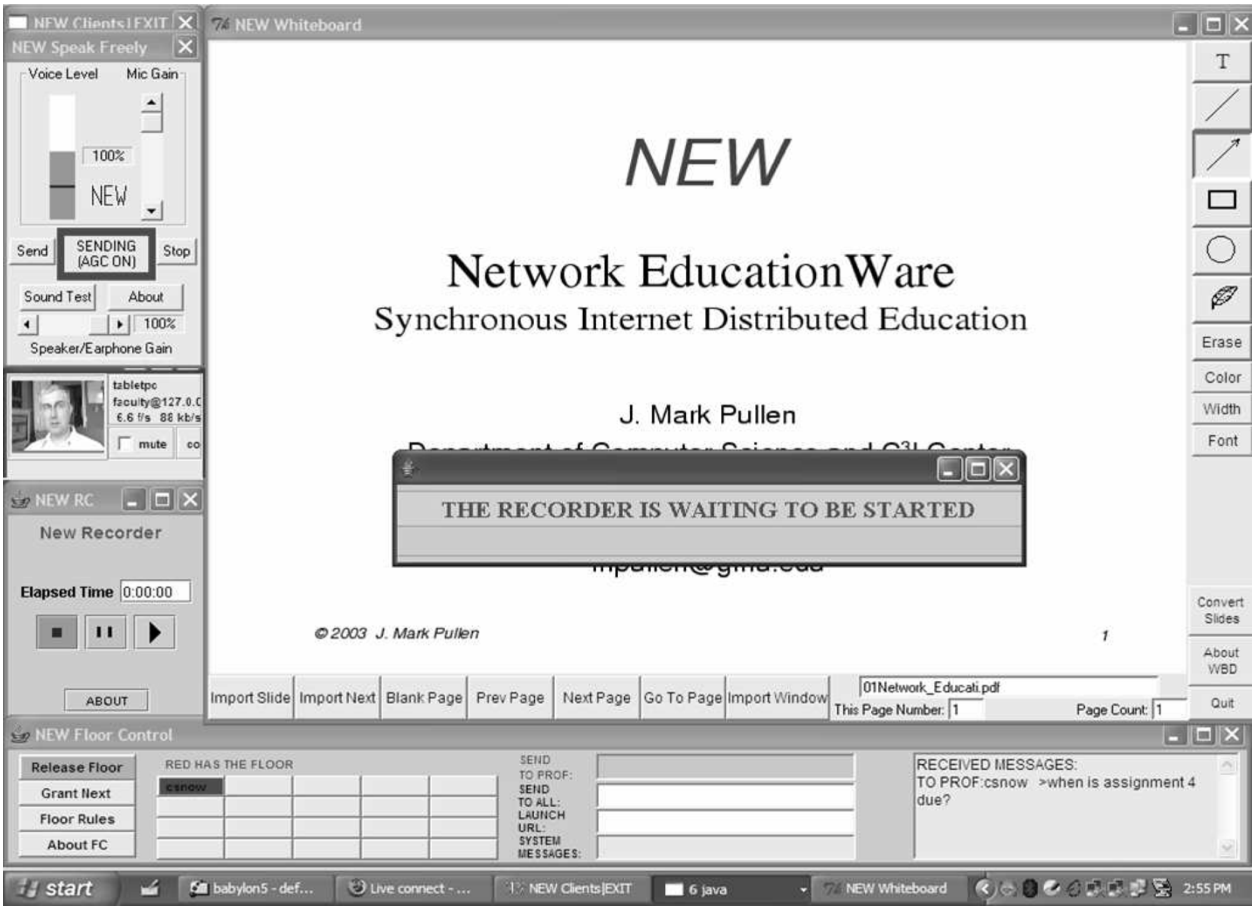
The authors are with the Center of Excellence in Command, Control, Communications and Intelligence, School of Information Technology and Engineering, George Mason University, Fairfax, VA 22030-4444 USA.

Digital Object Identifier 10.1109/TE.2005.854577

---

[1] OpenCourseWare website: http://ocw.mit.edu

0018-9359/$20.00 © 2005 IEEE



NEW

Network EducationWare

Synchronous Internet Distributed Education

J. Mark Pullen

© 2003 J. Mark Pullen

1

THE RECORDER IS WAITING TO BE STARTED

Elapsed Time 0:00:00

01Network_Educati.pdf

This Page Number: 1 Page Count: 1

RECEIVED MESSAGES:
TO PROF:csnow >when is assignment 4 due?

Fig. 1. Full user interface including video display with reminder to instructor to start recorder before starting lecture. Main components shown are (clockwise from top right) the whiteboard; floor control (across bottom); recorder control with buttons for stop, pause, and forward; Video Interactive Client (VIC) displaying video image of instructor; and a Speak Freely client showing audio level with vertical indicator (left); and (at top left) the master client "NEW Clients" tab controlling all of these. The NEW floor control components include access controls, participant grid box, and messaging area.

ical to learning? The ability to receive spoken and graphical content (e.g., slides and any annotations made on them), and to originate audio and video, can be provided by any modern personal computer. That ability, combined with a connection to the Internet, can offer students a strong sense of participation, only requiring infrastructure that is widely and cheaply available.

The term *simulteaching* describes the simultaneous teaching of a set of students in separate locations, some together in a classroom with the instructor. Irrespective of their location, students should have a strong sense of participation in the ongoing class, and critical to this feeling is the ability to interact with the instructor and their fellow students. Hardware and software are required that allow remote-location students to do the following:

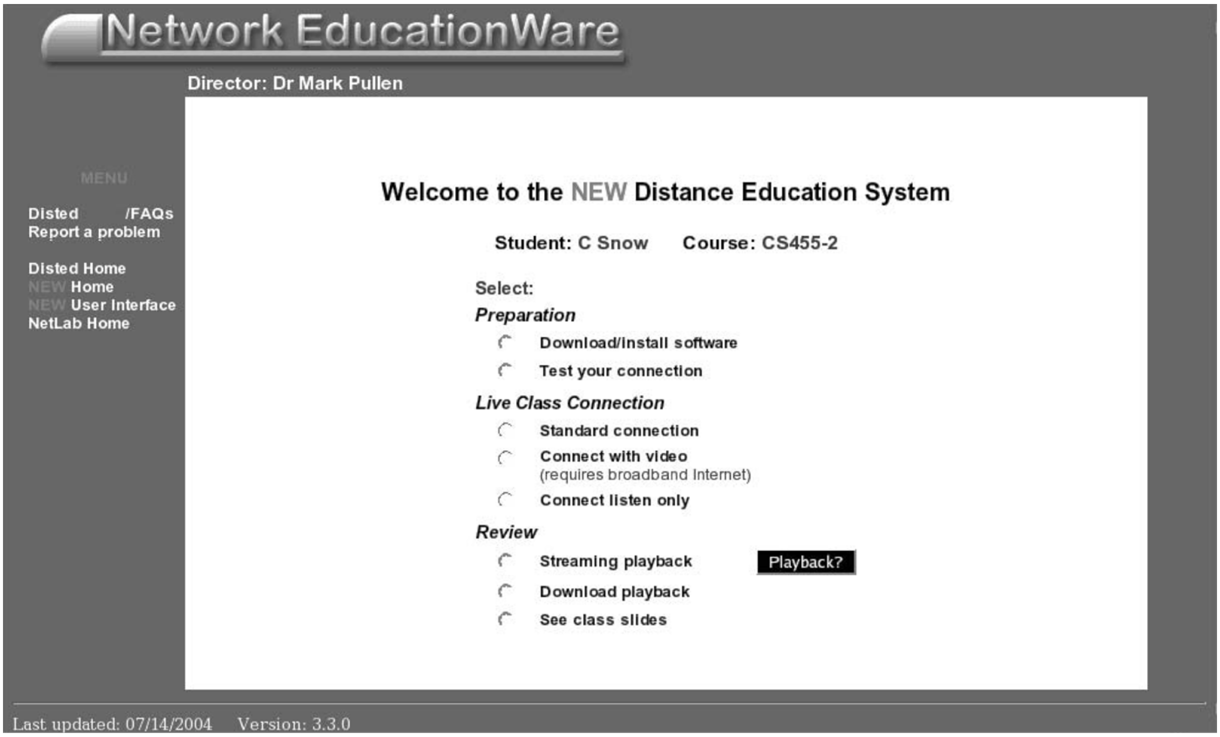
1) receive the live classroom content at any location while being assured that they do not lag the originating class;
2) ask and respond to questions in a natural way, e.g., by speaking;
3) interact with each other during class, the equivalent of a student asking a neighbor a question.

NEW has been developed to fulfill this need and provides many of the valued features both of smart classrooms and Web-accessible simulteaching. The NEW client runs on a typical student computer using dial-up modem, broadband, or direct Internet connection. The NEW server runs on inexpensive, off-the-shelf server platforms (e.g., Pentium- or Sparc-based).

NEW was designed to be have the following benefits.

1) *Convenient for students*: It provides students with the ability to participate synchronously in a live class experience, not simply hear and see the classroom presentation, and also provides a recording of the class for future playback.
2) *Convenient for instructors*: It minimizes change in presentation style and makes the system simple and easy to use when teaching so that the barrier to entry is low.
3) *Conservative in network capacity*: NEW delivers high-quality presentation over ubiquitous 56 kb/s connections.
4) *Conservative in capital and operating costs*: NEW requires no special hardware and minimal specialty software (see next point) and can operate comfortably on configurations that are, by today's standards, quite modest; administering NEW, even for several courses, is easy and does not require specially trained personnel.
5) *Entirely open-source*: All of these goals are achieved in an academic open-source, and eventually platform-neutral, implementation.

These goals, and how NEW meets them, are discussed in more detail below. Technical details of NEW components and



Network EducationWare

Director: Dr Mark Pullen

MENU

Disted /FAQs
Report a problem

Disted Home
NEW Home
NEW User Interface
NetLab Home

Welcome to the NEW Distance Education System

Student: C Snow **Course:** CS455-2

Select:

Preparation

○ Download/Install software
○ Test your connection

Live Class Connection

○ Standard connection
○ Connect with video
(requires broadband Internet)
○ Connect listen only

Review

○ Streaming playback Playback?
○ Download playback
○ See class slides

Last updated: 07/14/2004 Version: 3.3.0

Fig. 2. Student Web Portal Interface to NEW. The page is divided into three principal sections by function: 1) downloading software and ensuring it is operating correctly, 2) connecting to a live class (with or without video), and 3) accessing previously recorded material for streaming playback, downloading for local playback, or accessing the printed lecture slides.

their operation appear in the following section, followed by a discussion of experience using NEW over the past three years.

II. WHAT NEW OFFERS

A. Telecommuting to Class

NEW is designed to provide to students remotely connected by Internet the experience of attending and participating in a classroom presentation. That experience includes hearing the instructor's voice and seeing the material presented on a blackboard or screen, along with any annotations made by the presenter, e.g., some text underscored, or an arrow drawn pointing to a particular feature, or a problem solved. It also includes the ability to ask (or answer) questions by typing or speaking. Fig. 1 shows the NEW user interface. Considerable care has gone into the development of NEW to ensure the synchronous nature of the presentation, i.e., remotely connected students see what students attending the live presentation see with never more than a few seconds delay. The combination of text and graphics appearing on each slide, real-time annotations made on slides, and presenter's voice is referred to as *audiographics*, to distinguish it from video. NEW has been optimized to deliver its audiographic content in real time. Many simulteaching systems provide video of the presenter and sometimes also of the class. Video, an option in NEW, is delivered at 320 × 240 pixels with frame rates from 1 frame/s (slow scan) up to 30 frames/s, using a "Web cam." The inclusion of video is a management choice, since video consumes significantly greater network and system resources while typically adding relatively little value beyond that provided by audiographics [8].

NEW has been demonstrated in use over distances up to 10 000 km. However, its use may be confined to a regional scope as an administrative choice [9], recognizing that students benefit from nonclass activities and resources available on campus [10], even if students do not attend all classes regularly. Other considerations include the regional availability of low-cost dial-up and the need for students to appear on campus occasionally, e.g., to write exams. Over the course of the semester, students may miss one or more lectures. One university cites a typical absentee rate for any given engineering class of up to 20% [3]. Since the audiographic content of each class is recorded, students have the option of playing back a recorded lecture, as often as they like, at a later date. Students may choose to stream the data from a server, or download an entire recorded class, and then play it back locally. Typically, NEW recordings require approximately 5 MB/h of class time if the video is not recorded. Recently, one student living in Lebanon took a graduate course taught in the United States by downloading the recorded lectures (primarily because of the time differential) and playing them as time permitted. The student expressed great satisfaction with this delivery technique.

Simulteaching also offers to online students an analog of interacting with a fellow student in the classroom. A student may start or join a Web-based chat-room session with other students during a lecture, while continuing to receive the audiographic content of the class. This opportunity enables a student to "talk" to others (presumably about course content) in a way that is not disruptive to the class.

Students access NEW via a Web-driven portal (Fig. 2). The Web server provides authenticated students with access to live classes and to previously made recordings and slides presented in those classes [using Adobe Systems' popular portable document format (PDF)]. The recordings and slides can remain available to these students after the course is over, for consultation anytime, providing an online reference source. The Web portal also provides access to the client software so that students using the system for the first time can easily download and install the necessary components. Further, NEW is designed to be self-maintaining once installed. If a student connects to a server to access a class for which a newer version of any of the client components is needed, the software is automatically uploaded and installed prior to displaying the requested class.

B. Teaching Environment

Slides to be used in a NEW lecture can be produced using standard authoring tools able to produce PDF output. This capability results in time savings to instructors who need not attend training sessions in the use of specialized authoring tools and Web design and who often already have such teaching material. Further, NEW currently understands Microsoft PowerPoint and open-source LaTeX file formats and produces, automatically, the PDF format required for presentation and recording. During this automatic conversion process, handout versions of the slides can also be produced, to be placed on the Website for student download. Requiring the instructor to prepare the presentation does, of course, represent a significant investment in time, particularly when a course is first given online. However, in end-of-semester evaluations, students—even those who did not use NEW—report significant value in the more organized presentation.

An instructor presents a class by running a NEW client (Fig. 1). The only controls the instructor needs to master are those of the recorder (a button layout like most record/playback devices), the whiteboard (controls like those of any standard computer drawing tool), and the floor control, which allows control of who can speak (who "has the floor").

The NEW floor control provides several important functions beyond access to the floor. The grid box provides a visual indication of who is attending a class remotely and who currently has the floor, a means whereby instructors can send and receive typed information to or from remote users, and a way to launch for display a Web page on all users' computers (using the local browser client on each user's machine).

The whiteboard on which slides are shown allows instructors considerable latitude for annotation using simple shapes, arrows, and lines, all in various colors and thicknesses. Text may be typed onto the slide using the keyboard. Drawing or writing free-hand is also possible. Blank slides can be inserted at any point to allow further explanation or illustration. (These also become part of the recorded lecture.) The whiteboard also displays JPEG images, HTML, ASCII text, and video (but the video file must be preloaded on client machines).

Perhaps the most significant change for a simulteaching instructor is presentation etiquette. Since typed-in student questions and comments sent "TO PROF" (Fig. 1) are not recorded, nor visible to all participants, instructors need to adopt the habit of repeating these items for the benefit of the live class and the record. Similarly, student responses in the live class often are not captured by the instructor's microphone, and also need to be repeated. This practice is not difficult to adopt and can be of value in any class presentation. In addition, directing some questions specifically to the remotely connected students strengthens their sense of involvement in the class.

All of the work of preparing and presenting a class using NEW can be performed on a single computer. Any contemporary notebook computer is a suitable platform, though a tablet-style display (with stylus for writing or drawing) is highly advantageous for presentation purposes.

For simulteaching, a classroom with a projector for computer displays is preferred so as to provide a "normal" setting for students attending the live presentation. NEW normally is run on a computer in the classroom. However, NEW allows a class to be both originated and received from *any* location providing computer and network access, e.g., home, office, café, or classroom. Snow days may become a thing of the past.

C. Effective Over Low-Capacity Connections

NEW was designed to deliver its audiographic content over standard 56 kb/s dial-up lines. Video is optionally available over higher performance connections if provided by the instructor and selected by the student.

The instructor audio is compressed using standard GSM compression; the resulting 20 kb/s stream delivers clear, intelligible audio. The software guarantees that audio always has priority in delivery. The slide pages are not pre-fetched by the client; the slide content is sent to participating clients when the instructor asks for that page to be displayed. Current versions of NEW limit the size of an individual page to 64 KB (9.4 s at 56 kb/s). Pages larger than this are converted automatically to a JPEG image, which can represent more graphical detail within the 64-KB limit. Slides containing only text are typically 15 KB or smaller; even if audio consumed its full 20-kb/s bandwidth during a slide transfer, the effective TCP throughput offered by a 56-kb/s link, $\approx$40 kb/s, would still deliver a slide in 6 s. Annotation objects (lines, arrows, or boxes), at a few hundred bytes per object, take under 1 s to transfer.

Annotation graphics require minimal network capacity, typically only a few hundred bytes per annotation object. The "free-hand" tool generates the most traffic (a few hundred bytes per written character), but as the client is rate limited, annotations do not interfere with audio. The rate limit is configurable (see end of Section II-D) and can be relaxed to capitalize on higher capacity connections if these are available (but not to the point where audio quality is sacrificed). Higher capacity connections allow new slide pages to be downloaded more quickly, hence displayed sooner.

D. Inexpensive to Set Up and Operate

Some existing commercial products, e.g., Centra or Microsoft LiveMeeting, equal, and may surpass, NEW's capabilities; however, these are expensive for many academic institutions to employ. NEW was created as an affordable alternative for synchronous and asynchronous education.

The major expenses in operating any such system are the capital outlay to establish infrastructure and the ongoing operating costs, notably administrative personnel. A recent study of online learning finds that the best return on investment is achieved with simulteaching, as opposed to asynchronous teaching tools [11]. The same report analyzed the costs and rewards of online courses. Factors that raise costs include capital equipment (mainly servers), personnel, and support for users, e.g., training faculty to use new authoring tools. NEW was designed to use commodity, off-the-shelf equipment and software and can be administered by anyone with modest administration computer skills; no specialized personnel or training is needed.

NEW operates in client–server mode. Students and instructors run the client; the server handles the set up of connections, user authentication, and content delivery (Fig. 3).

Client software is downloaded and installed via the Web portal. At present, the client runs only under the Windows family of operating systems ('98 or more recent), but its availability to Linux and Macintosh users is planned. Students use the NEW Website to access the client software and invoke an automated procedure for its installation on their computers. Little administrative overhead is associated with student or staff client installation. For the few cases when users need assistance (most often, at the start of the semester), systems staff must be accessible.

In terms of capital outlay, the client requires only a Windows platform with a 300-MHz Pentium-III CPU, 256 MB of memory, audio (with microphone if the user wishes to originate speech), and a network connection of at least 56 kb/s. The client needs 20 MB of disk space beyond what the needed Java run-time environment requires (typically 35 MB). Instructors wanting to provide video with a lecture would add a camera and any needed video capture hardware to this configuration and at least a 600-MHz processor. Instructors generally find it advantageous to run the client on a computer that has a tablet and stylus interface.

The NEW server is a Java application and can run on any Linux/UNIX or Windows platform. A Linux system running on a 1.8-GHz Pentium-III with 1 GB of memory, on a 100-Mb/s network connection, is used to handle up to 40 simultaneous participants, and does so easily. Similarly, a Sun UltraSparc 60 with 1 GB of memory handles 30 users comfortably, while running many other services concurrently. The entire server system requires roughly 100 MB of disk space plus 500 MB per course per semester, primarily for recordings. In some cases, organizations are retiring machines of this caliber; hence, servers may be available at no cost.

Installation and operation of the NEW server-side components (NEW server plus Web site) are now largely automated and can be performed by ordinary technical support personnel in one or two hours. A single NEW server is designed to operate many courses per semester. The logistics of managing course content and administrative data (e.g., user accounts) are handled through the same Web portal that students use to access content. The layout of administrative functions is straightforward so that no special technical skills are required for site administration, further reducing operating costs.

The concentration of student, instructor, and administrator access to NEW via a single, and largely self-installing, Web portal is a significant step in achieving ease of use for each user constituency and reducing management cost.

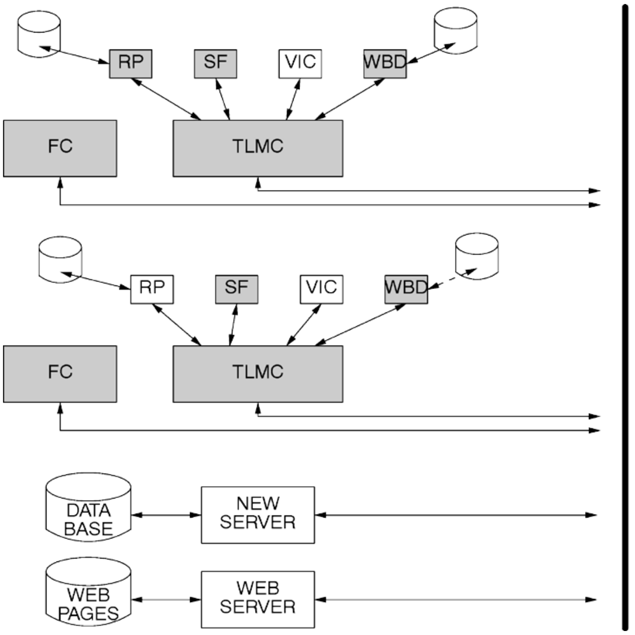


Fig. 3. Schematic representation of NEW system structure showing two client instances and a server. FC: Floor control; RP: record/play control; SF: speak freely; VIC: Video Interactive Client; WBD: whiteboard; and TLMC: Transport Layer Multicaster Client. The topmost client instance depicts the components in active use (shaded) by an instructor: the WBD is displaying slides (from files) along with any annotations; SF is capturing voice from the instructor microphone; and RP is recording the audiographics. In this case, the instructor elected not to use video. FC is letting the instructor communicate with students and displays a list of those connected (including the instructor). All of these components typically run on a tablet notebook computer. A student participating in the live class uses an identical client but only uses WBD and SF to receive the audiographics, and FC in order to ask (or answer) questions.

The same client software is used both by students to participate in a lecture and by instructors to give the lecture; the only distinction is in the start-up configuration. Both students and instructors use the Web portal to connect. Students are offered the choices shown in Fig. 2; instructors are presented more options. All clients are instantiated by an eXtensible Markup Language (XML) script delivered from the Website in response to the user's request. Thus, students never need to interact directly with the client software they downloaded; by selecting a live class or a playback connection, they receive an XML script to be interpreted by the client software, which launches appropriate components of NEW and establishes connections as necessary. This capability provides for both ease of use and ease of maintenance.

The Web-based model scales very well. The number and data rate of connections supported is more a network capacity restriction than one imposed by NEW. The use of XML configuration files for clients means that different courses (even different sections of a course) can be steered to different server processes (running on the same or different machines). The use of a database makes management easy for operational information of large communities and many courses. The database administration function requires little time for small courses but can become significant if large numbers of students are supported.

E. Open Source

"Open source," a widely used term, often is misunderstood to mean software that is completely free (of cost or of terms of use). In fact, *open source* refers to software in source-code form, belonging to a particular author (individual or group), made available for use by others, subject to terms and conditions of a license agreement and without monetary consideration to the author [12]. Users may make use of the source code for its intended purpose, or adapt it for use in projects of their own, subject to limitations set forth in the license. NEW is available as "*academic* open source" meaning that while the developer at all times retains ownership of the code, that code may be freely distributed and used in any educational or governmental setting. Others may further develop NEW for their own purposes and allow their work to be added to future releases in the spirit of open source.

Indeed, that very freedom of access to code has been used in building NEW; the next section describes its major components, some of which originated as open-source projects elsewhere. Commercially distributed software, e.g., [13], is available only as long as a company remains in business to provide it. NEW was developed as purely open-source software so that it will always be available. The open source license and code itself are available at the Website http://netlab.gmu.edu/NEW.

One feature offered by NEW requires proprietary code. The automatic conversion to PDF from PowerPoint slides requires Microsoft code, which the user will already have if the user has PowerPoint. This limitation may soon be relaxed with the planned integration of components of OpenOffice, an open-source suite of document manipulating tools.

III. NEW TECHNOLOGY

At its heart, the reason for the existence of NEW is group communication: teaching or conferring with a group of people. A well-developed networking technology, multicasting, exists for this purpose. Where it is deployed, multicasting allows a single network transmission to be delivered to a group of receivers [14]. Unfortunately, network-level multicasting has not been deployed across the general Internet and so cannot be used for NEW, even though a number of excellent tools have been developed to take advantage of its power for group communications [15]. In fact, NEW does use three such tools: SpeakFreely, WBD, and VIC. The NEW Live Server was first developed as the Transport Layer Multicaster (TLM). Working over a point-to-point connection with each Master Client, the TLM delivers one-to-many transmissions to the tools in the same format as network multicasting, although without the high efficiency that is theoretically possible with network multicasting. However, a compensating advantage exists with a TLM server hub; NEW is able to use the Internet Transmission Control Protocol (TCP) to link client and server. As a result, NEW traffic can reach systems behind Network Address Translation (NAT) gateways or firewall systems that would be nearly impossible to reach with real multicast traffic.

The audio receive/send component is arguably the most important in NEW because it is critical to the students' experience and because conveying voice with good quality over the Internet at a low data rate presents a big challenge. Walker's open-source SpeakFreely (SF) [16] meets that challenge. NEW adds a graphical interface that provides all needed user functions (upper left of Fig. 1).

The other critical element for teaching online is graphics. The whiteboard (WBD), an open source project originally created at Loughborough University, Leicestershire, U.K., provides a shared graphic presentation medium that displays precomposed graphic content provided in any of several open formats, most important, PDF, and annotations in real time. A tablet-and-stylus interface offers a natural interface (compared with a mouse and traditional display), encouraging the use of the whiteboard as a surrogate chalkboard, rather than merely a screen on which to display slides.

While all NEW classes have audiographic content, video is optional. NEW uses an excellent video tool called VIC, originally developed at the University of California at Berkeley (UCB) and the Lawrence Berkeley National Laboratory [17], and is compatible with ITU standard H.323. A typical delivery rate is two frames of 320×240 pixels/s, but rates up to 30 frames/s are possible. Video is available to NEW users with network connections of 200 kb/s or higher.

The audio, graphics, and optional video originating from all tools associated with a given user are collected, rate-limited giving audio priority, encapsulated, and sent over a single network connection by the Transport Layer Multicaster Master Client (TLMC). Similarly, TLMC distributes received data to the appropriate clients. It coordinates the configuration and launch of other NEW components needed for a particular session. Which clients, and their network configuration, is established by TLMC responding to the XML file returned by the supporting Web server at the beginning of a NEW session or from a local file when running stand-alone. The separate floor control (FC) client manages sending permission in conjunction with TLM and TLMC.

The recorder components—record (REC) and record control (RC)—capture a time-stamped stream of messages as seen at a particular user's workstation and record them to disk for playback. *RC* is controlled using a VCR-like start/stop/pause interface for REC, with a display of status and a time counter (lower left of Fig. 1). Analogously, playback (PLAY) and playback control (PC) components regenerate the original stream of messages from a time-stamped recording. PLAY can function either as a playback tool for one user or as a server, streaming playback to multiple users. In either case, the same clients (TLMC, SF, WBD, and optionally VIC) provide the user interface.

NEW's server side uses the open-source MySQL database, which accepts SQL queries from the Web server supporting the NEW Web portal, and provides responses used to generate response Web pages dynamically. Using a database is a practical necessity to gain easy control over the large amount of data generated when NEW is used to operate multiple courses per semester. The Web portal through which NEW users access content is provided using the open-source Apache Web server with the scripting language PHP [18], also open-source.

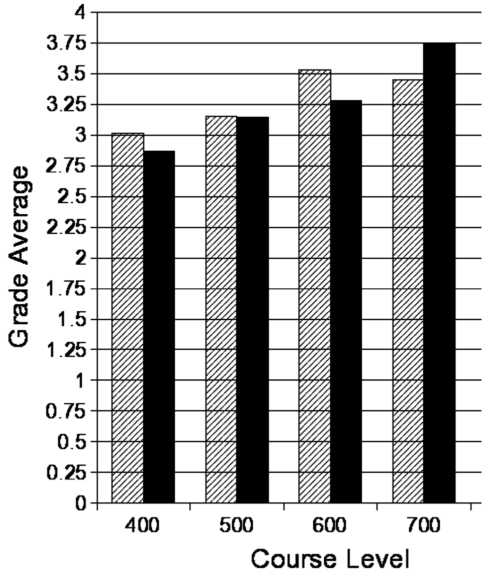


Fig. 4. Comparison of grade averages between classroom attendance (hatched) and distance-education (black) students across range of courses from undergraduate to graduate.

IV. EXPERIENCE WITH NEW

NEW made its debut in summer session 2002, when it was used for two courses. In the spring semester 2004, it served a total student population of about 2500 and was used in 12 courses per semester in Computer Science, Information Technology, and Health Science.

NEW has been used primarily to present live classes (i.e., as the presentation and recording component of a smart classroom) but is not limited to this setting. NEW has been used to provide simultaneous live lectures at two campuses with the instructor at one and a teaching assistant at the other.

The actual set of students attending any given live lecture has been observed to vary through the semester. Some students enroll in the "NET" section of a course but prefer to attend live classes; the converse also occurs. The nature of the classes is such that a student who attends one class online can easily attend the next in person. Students consistently rate highly the value of the lecture recordings; reasons include the ability to time shift a lecture to fit better with their schedule, to be able to handle interruption in cases where the entire lecture time cannot be allocated (some classes are 2.5 hours long), and the ability to replay part of a lecture to review a particular topic.

In each of the semesters where NEW has been used, no significant difference has been observed in student performance as reflected by grades (Fig. 4).

At the end of each semester when NEW has been used, students have been surveyed concerning their satisfaction with NEW and reasons why they used it. Fig. 5 displays the results of four questions on the survey. One notes that students were very positive in their response to the question asking if they would take another course using NEW.

V. PLANS FOR NEW'S FUTURE

There is room to extend NEW; its highly modular architecture facilitates such efforts, which are ongoing under various sponsorships.

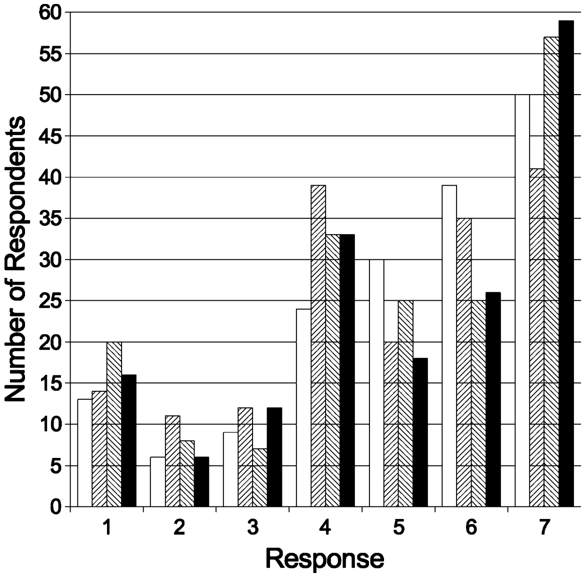


Fig. 5. Responses to four survey questions (left to right, white to black): 1) satisfied with learning online, 2) learned as much via NET as in person, 3) would take another course with network option, and 4) network option was more convenient. Score range: 1—strongest disagreement to 7—strongest agreement. Note: The response 4) was treated as "no opinion" or "not applicable" by many students.

For example, one recently completed government-sponsored project enabled encryption of all content in or out of a client so as to guard against release of content for government use. This extension made use of OpenSSL, an open-source Secure Sockets Layer package, to handle authentication (of server to client and client to server) and subsequent encryption of content. This feature will make NEW usable by those whose needs include ensuring that content is protected. The same project also provided the ability to cut and paste from any displayed window to the whiteboard, thereby facilitating interaction between users needing to discuss what one of them "sees on the screen."

The design of NEW's display components and controls (specifically their reliance on Unicode) offers easy extension to multilingual operations, making NEW suitable for users of languages other than English. In a similar vein, adding metadata to recordings and the recording of typed notes are planned, as is the ability to Web-link to a particular NEW recording for playback.

Another interesting possibility is to provide on-command running of Java applets, giving NEW a kind of platform-neutral animation. Also planned is an expansion of NEW's video playback facility to provide for background uploading of video clips that can then be played on demand.

Another ongoing effort is working to port the NEW client component suite to Linux/UNIX and to Apple OS X, expanding availability by 2006.

VI. CONCLUSION

This paper has described Network EducationWare, an open-source system for synchronous distance education via the Internet. While much deployment of computer and network technology in the area of education is focused on smart classrooms and making content available asynchronously to distance students, NEW is oriented toward providing to distance students many of the valuable aspects of the live classroom experience that are essential for learning. NEW achieves this ability using inexpensive and commonplace hardware, as well as software that is freely available under an academic open-source license. NEW is successful in providing convenience to students who can participate in a class, whether they attend in person or telecommute, and in making available recordings of classes for playback. It imposes little or no change in the way class presentation material is prepared, and mastery of the technology for teaching is very easily accomplished. NEW is attractive to course administrators since it is inexpensive to set up and operate, the latter because of a well-designed and simple-to-use Web portal offering clear access to vital management functions and requiring no specialized personnel or training.

NEW has been in use for three years, growing from two to 12 courses per semester and to a student community of over 2500. Its use has grown beyond the information technology and engineering courses, where it was first used, to include courses in the medical field. The expansion of NEW's capabilities continues to extend its utility and power as a distance education system.

REFERENCES

[1] H. E. Pence, "What is the role of lecture in high-tech education?," *J. Educ. Technol. Syst.*, vol. 25, no. 2, pp. 91–96, 1997.

[2] T. Waits and L. Lewis, "Distance education at degree-granting postsecondary institutions 2001–2002," National Center for Education Statistics, Washington, DC, Tech. Rep. NCES 2003-017, Jul. 2003.

[3] L. Winer and J. Cooperstock, "The 'intelligent classroom': Changing teaching and learning with an evolving technological environment," *Comp. Educ.*, vol. 38, pp. 253–266, 2002.

[4] J. Wilson, "After the fall: The lessons of an indulgent era," presented at the Annu. Conf. Distance Teaching Learning, Madison, WI, Aug. 13–15, 2003.

[5] J. Wirt, S. Choy, P. Rooney, S. Provasnik, and R. Tobin, "The condition of education 2004," National Center for Education Statistics, Washington, DC, Tech. Rep. NCES 2004-077, Jun. 2004.

[6] I. E. Allen and J. Seaman, "Sizing the opportunity: The quality and extent of online education in the United States, 2002 and 2003," The Sloan Consortium, Tech. Rep., Sep. 2003.

[7] D. E. Gerald and W. J. Hussar, "Projections of education statistics to 2013," National Center for Education Statistics, Washington, DC, Tech. Rep. NCES 2004-013, Oct. 2003.

[8] J. M. Pullen, "Applicability of internet video in distance education for engineering," presented at the IEEE Frontiers in Education Conf., Reno, NV, Oct. 2001.

[9] J. M. Pullen and P. McAndrews, "Low-cost internet synchronous distance education using open-source software," , to be published.

[10] L. Carswell, "The 'virtual university': Toward an internet paradigm?," *ACM SIGCSE Bull.*, vol. 30, no. 3, pp. 46–50, Sep. 1998.

[11] C. Goodwin and M. Bowman, "Is the bottom line of online out of line? Calculating the total cost of online courses in technology curricula," presented at the *Proc. Amer. Soc. Engineering Education Annu. Conf. Exposition*, Salt Lake City, UT, Jun. 20–23, 2004.

[12] A. M. S. Laurent, *Understanding Open Source and Free Software Licensing*. Cambridge, MA: O'Reilly & Assoc., 2004.

[13] J. M. Pullen, "Synchronous distance education and the internet," presented at the Int. Networking Conf. (INET), Geneva, Switzerland, Jul. 21–24, 1998.

[14] M. Macedonia and D. Brutzman, "Mbone provides audio and video across the internet," *IEEE Computer*, vol. 27, no. 4, pp. 30–36, 1994.

[15] M. H. P. Kirstein, M. A. Sasse, and S. Clayman, "Recent activities of the mice conferencing projects," presented at the Int. Networking Conf. (INET), Honolulu, HI, Jun. 27–30, 1995.

[16] J. Walker. (2004, Jan.) Speak Freely. [Online]. Available: http://www.fourmilab.ch/netfone/windows/speak_freely.html

[17] S. McCanne and V. Jacobson, "Vic: a flexible framework for packet video," in *Proc. 3rd ACM Int. Conf. Multimedia*, San Francisco, CA, Nov. 5–9, 1995, pp. 511–522.

[18] L. Ullman, *PHP and MySQL for Dynamic Web Sites*. Berkeley, CA: Peachpit Press, 2003.

Charles Snow (M'91) received the Ph.D. degree in computer science from McGill University, Montreal, QC, Canada, in 1998.

He is currently a Research Assistant Professor at George Mason University, Fairfax, VA, teaching courses in computer networking and operating systems and working in the Networking and Simulation Laboratory in the C4I Center. His main interests are pervasive computing and the effective application of technology to the areas of education and medicine.

J. Mark Pullen (S'70–M'74–SM'82–F'91) received the B.S.E.E. and M.S.E.E. degrees from West Virginia University, Morgantown, in 1970 and 1972, respectively, and the Ph.D. degree in computer science from George Washington University, Washington, DC, in 1981.

He is currently a Professor of computer science at George Mason University, Fairfax, VA, where he heads the Networking and Simulation Laboratory in the C4I Center. He teaches courses in computer networking and has been active in the research fields of distributed virtual simulation and distributed teaching environments.

Dr. Pullen is a Fellow of the Association for Computing Machinery (ACM). He is a licensed Professional Engineer.

Priscilla McAndrews received the B.A. degree in mathematics from Vanderbilt University, Nashville, TN, in 1968, the B.S. degree in computer science from the University of Missouri at Kansas City, in 1991, and the M.S. degree in computer science from George Mason University (GMU), Fairfax, VA, in 1995.

She is currently the Laboratory Manager and a research contributor in the areas of Web-based distributed systems in the Networking and Simulation Laboratory in the School of Information Technology and Engineering at GMU.